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Overview of MAGIS: A Multi-Resource Analysis and Geographic Information System

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Abstract—MAGIS is computer software for planning land management and transportation-related activities on a geographic and temporal basis in the presence of multiple and sometimes conflicting objectives. The focus is on tactical planning, and MAGIS can be operated in both optimization or simulation modes. MAGIS is integrated with a commercial mathematical programming package, GIS software for data input and display of results, and an optional tree growth simulator. It contains interactive, mouse-driven screens and operates in the Windows environment on a 486 or higher personal computer.

Keywords: tactical planning, transportation analysis, optimization, GIS

Natural resource managers are now challenged to fulfill many conflicting social, biological, and commodity production objectives. These include providing habitat for terrestrial and aquatic organisms, producing commodity outputs such as forage and sawlogs, and providing recreational access and use. The spatial arrangement of vegetation and timing of land management activities are often critical to the achievement of the stated objectives. In addition, the planning process has become more complex due to increased public involvement, the required processing of larger quantities of data, and the necessary integration of various simulators and models.

As a result, a negotiated planning tool is needed that combines Geographic Information System (GIS) with modified versions of existing predictive models and optimization methods (Dean 1994). New tactical planning tools, such as MAGIS, can help natural resource managers meet these challenges (Zuuring 1992).

MAGIS, a microcomputer-based spatial decision support system (SDSS), was developed jointly by the Montana Department of State Lands, the University of Montana, and the Intermountain Research Station, Forest Service, U.S. Department of Agriculture, to provide natural resource managers with a sophisticated planning and decisionmaking tool. A SDSS consists of a data base management system (DBMS), analytical models, a graphical display and report generators (Armstrong and others 1986). Such a system should also be able to incorporate new tools and methodologies as they become available (Keen 1980). MAGIS is a highly flexible, tactical/operational planning tool for solving a wide variety of natural resources management problems. Data that define any resource planning problem come from a series of input screens and files imported from a GIS. Through a comprehensive setup procedure a planning model is formulated, a mathematical programming matrix is generated, and a feasible solution is computed if possible. In addition, MAGIS possesses capabilities to manually override resource allocations and simulate alternative strategies that can be compared with one another.

Solution summary statistics as well as tabular reports can be sent to the monitor screen or saved to a file. In addition, the sequence of land management and transportation network activities specified in the planning problem solution can be displayed geographically on a digital map.

MAGIS has no regional or geographic limitations because all data are user defined. An optional growth and yield model is linked to MAGIS but is not essential to the formulation of planning models. Likewise, different GIS software can be used to display the spatial and temporal distribution of solution quantities provided that the GIS exports and imports DBF or

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ASCII formatted files. Work is under way to provide graphical user interfaces for data entry and editing using Digital Line Graph (DLG) vector data files (U.S. Geologic Survey 1989).

Description

MAGIS integrates three commercial software packages (which are described below) through the use of one common user interface. MAGIS executes under Microsoft WINDOWS v3.1 on a 486-class microcomputer. Input/output requirements and program execution are controlled by a system of computer programs written in the FOXPRO and DATAFORM programming languages. Both languages are associated with DBMS's.

MPSIII/pc, a commercial mathematical LP package (KMS, Inc. 1992), consists of several modules but only MIPIII, a mixed integer programming solver, C-WHIZ, a linear programming optimizer, and a run-time version of DATAFORM, a special data base management system, are required.

SPS (Arney 1985; Arney and others 1993), a tree growth simulator, is optional. If growth and yield data are not predicted by SPS, look-up tables containing growth percentages must be provided.

PAMAP GIS MAPPER (EPS, Ltd. 1994), a graphics interface able to display vector and raster data and having theming and querying capabilities, is optional. It is used to display planning model solutions in a spatial context. This is accomplished by linking solution attributes via a key or index to locations on a map. A similar linkage is being developed for ArcView 2 (ESRI, Inc. 1994). Linkages to other GIS software could likewise be created. A generic graphics interface is being developed that will accept vector data in Digital Line Graph (DLG) format to facilitate some aspects of data input such as defining security areas, wildlife corridors, or setting management options into the planning model solution.

FOXPRO, a data base management system, is not needed to execute MAGIS. However, DBF files are used to import attribute data linked to geographic locations.

The user interface consists of two horizontal menu bars and associated pull-down menus. Items are selected by "clicking" with a mouse and extensive use is made of radio buttons, scrollable windows/lists/tables, control panels, and customized data input screens. There is error checking/trapping with informative on-screen messages for data input via screens and data imported from external sources. A context-sensitive, on-line help facility is present.

MAGIS schedules land management and transportation-related activities on both a geographic and temporal basis. The focus is on tactical/operational planning conducted by an interdisciplinary team. The planning horizon can be up to five periods of equal or unequal length. A planning model is defined through a combination of decision variables and resource management (land and/or transportation) relations.

Land management options are defined by a combination of silvicultural treatment and logging method (if appropriate). Other multiple-use treatments such as prescribed burning can be scheduled. Transportation-related activities can be characterized by permanent or temporary road construction or reconstruction (by type and option), closing and re-opening of roads (by time period), road obliteration, and traffic routing. The latter is influenced by traffic direction (one or two way), flow capacities and traffic termination locations. Outputs can be calculated by network links and can include sediment yields over time.

MAGIS can be run in two solution modes: optimization and simulation. In the optimization mode either continuous or mixed-integer solutions can be specified for land management and transportation-related activities. Economic (for example, net revenue) or physical (for example, sediment loading) objectives can be maximized or minimized. A wide variety of multiple-use and environmental objectives can also be specified in the form of constraints and may be applied to the entire area modeled or geographic subsets (for example, specific drainages). In the simulation mode decision variables are "preselected" by the user to conduct "what if" analyses.

Management objectives are formulated as relations, any one of which can be designated as an objective that can be maximized or minimized or as constraints to be satisfied. Examples of such goals include: the acreage in a specific successional stage; the acreage having unique stand characteristics (such as density, height or diameter categories); the number of miles of open road; the number of acres in forage production or cover; wildlife security areas and corridors; the size of openings created by land management activities; timber harvest volumes by species; and costs and net revenues. All relations can be applied to the entire planning area or portions thereof such as drainages or wildlife zones.

Data Input

Data for MAGIS are of two types: forestwide and area-specific. The former deals with forestwide conditions that can be used repeatedly to analyze new areas and need only be entered once. The area-specific data are entered each time a new planning model or specific area is defined. These data are imported from a GIS environment and can be modified as needed.

Forestwide Data

Forestwide data are divided into four types: general, network project, land management project, and cost/price changes.

General data deal with such things as attribute names and classes, species and habitat type group names and members, and output specifications. The user defines zones and attributes that are used to build cost and output relationships.

Network data include project definitions for links (road types and options), traffic definitions, travel times, road maintenance/project costs, output specifications for the network projects, and traffic.

Land management project data incorporate management regimes with associated resource activities and costs, logging methods, harvest and timber strata specifications, successional stages, wood prices, output specifications, and growth and yield data coming either from the SPS tree growth simulator or entered directly as percent growth by strata.

Cost/price changes can be assigned to the inputs and outputs of network and land management projects by time unit.

Area-Specific Data

Area-specific data are of two types: graphics (spatial data) and attributes (nonspatial data). The required graphics include treatment units, stands and transportation network links (figs. 1 and 2). The nonspatial numeric data are divided into four types: stand and treatment unit specifications; network specifications; resource management relations; and special relations.

Stand and treatment unit specifications include their associated attributes. In addition, the treatment unit data include the stand acres that compose each unit and the land management project options (defined in the forestwide data) to be applied to the units.

Network specifications deal with existing and new network links and their associated attributes such as length and percent grade; the destination locations where network traffic terminates; and the project options (defined in the forestwide data) to be applied to network links.

Resource management relations are specified as being one of six types: timber output, nontimber output, acreage control, length control, cost, and net revenue.

Special relations consist of four types: adjacency, security areas, corridor sets, and resource-to-road triggers. Adjacency requires the specification of which vegetation treatments are to be excluded on adjacent treatment units. Security areas are defined so that user-specified management activities are restricted at certain periods or over the whole planning horizon

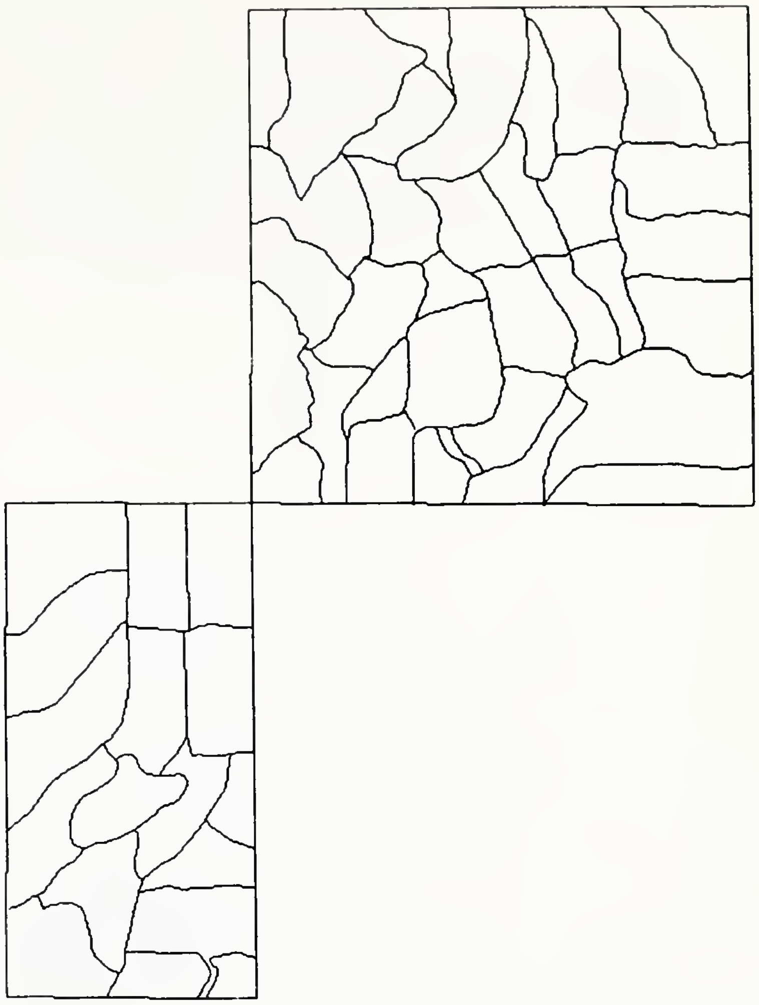

Figure 1—Portions of two sections containing 52 treatment units for the Swan State Forest, Condon, MT.

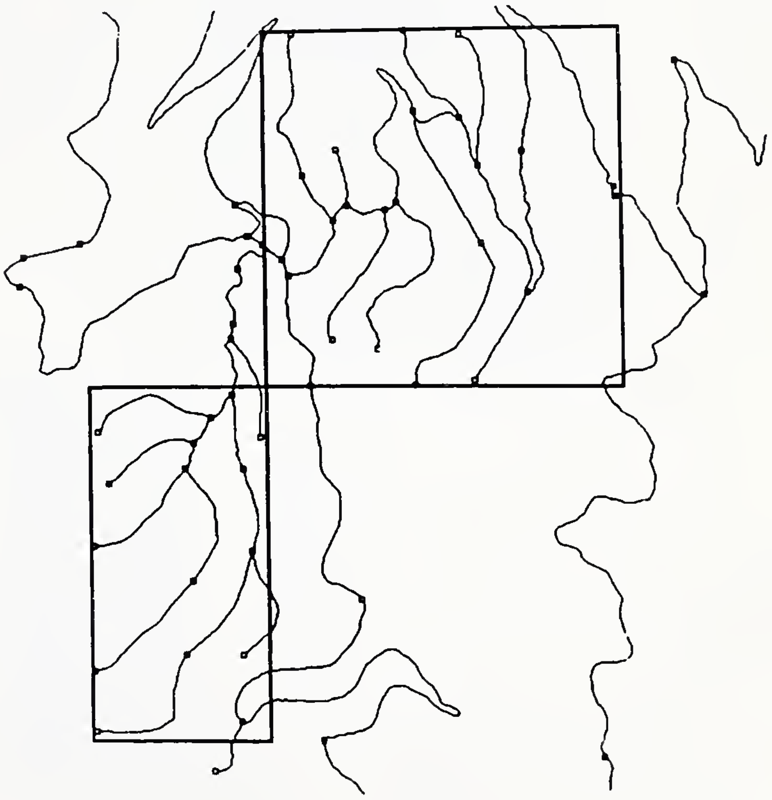

Figure 2—A typical transportation network consisting of links with starting/ending nodes for the Swan State Forest, Condon, MT.

by zone. Corridor sets define alternative routes of connected treatment units between a source and a destination. From these alternative routes, one is chosen that maintains certain acceptable successional stages throughout the length of the corridor. Resource-to-road triggers specify that certain road links are either required or excluded if a particular management regime is selected for a certain treatment unit.

Building Management Scenarios

Once the data are entered and processed, the SETUP procedure is used to enter the specifications for building a management scenario. A management scenario involves the selection of land management projects, network link projects, and traffic routing to the traffic termination locations. Four tasks must be completed by the user before a solution can be obtained for a management scenario. They involve specification of the following: solution controls, management constraints, decision variables, and special relations.

Solution controls refer to the analysis type and the objective to be maximized or minimized. The available analysis types are linear programming (land management projects and network link projects may be selected at fractional levels); mixed-integer programming (either network link projects must be selected in their entirety while land management projects may be fractional, or both land management and network link projects must be selected in their entirety); or simulation where the user chooses only those land management projects and network link projects of interest and uses the solution process in MAGIS to predict the outcomes of these choices. The objective function to be maximized or minimized is selected from the six types of resource management relations built during the data input phase.

Management constraints are another way of achieving specified objectives. They are defined by placing lower or upper bounds or both on any of the six types of resource management relations.

Preselecting decision variables is another feature of SETUP. Users can preselect land management projects, network link projects, close specified road segments to traffic, specify how much traffic of each type must be routed to each traffic termination location, and choose wildlife corridors and security areas. This feature permits the selection of projects for the simulation analysis type. It also allows overriding of the solution process in the linear programming and mixed-integer programming analysis types when asking "what if" questions.

Another feature of SETUP is the ability to "turn on or off" each of four types of special relations. Finally, SETUP has a utility for copying the SETUP specifications from a previously built management scenario, and for importing a solution from a previously solved management scenario back into the SETUP phase. The latter is useful for making minor modifications when addressing "what if" questions in the simulation mode.

Outputs

Outputs from management scenarios can be displayed as tabular reports or GIS-based graphics.

Tabular reports consist of solution statistics (objective function name and value, feasibility status, and so forth), resource management relations (value of resource management relation, limits imposed, and shadow price), and decision variable information (land management and network projects selected, traffic quantities on the network links, and so forth). Tabular reports can be generated for the current or previously solved and saved management scenarios. By default, reports are displayed on the monitor that can optionally be sent to a printer.

GIS-based graphics display several types of information associated with network links and treatment units in both spatial and temporal contexts. This is accomplished through theming variables and the use of color codes and crosshatching patterns. For example, the spatial and temporal scheduling of land management projects, road construction and reconstruction, road closing and opening or traffic flow can be displayed singly or in user-defined combinations (fig. 3). Additionally, the contribution made to a resource management relation by the projects selected for a management scenario can also be displayed, for example sources of sediment loading in a management scenario (fig. 4), or the distribution of successional stages resulting from management activities (fig. 5), or the distribution of costs or net revenues associated with activities across a planning area. Finally, security areas and corridor routes selected in a management scenario can be displayed graphically.

Performance

Since MAGIS is a new modeling system, performance data are limited for predicting the processing time required to develop management scenarios. It is clear, however, that the processing time will vary by the specifications made in SETUP, as well as by the data entered in the planning model-building phase. In particular, the processing time will vary by analysis type. Processing time for a simulation will be very fast (a few minutes or less). For linear programming the processing time is expected to be slightly longer while the mixed-integer types will require much

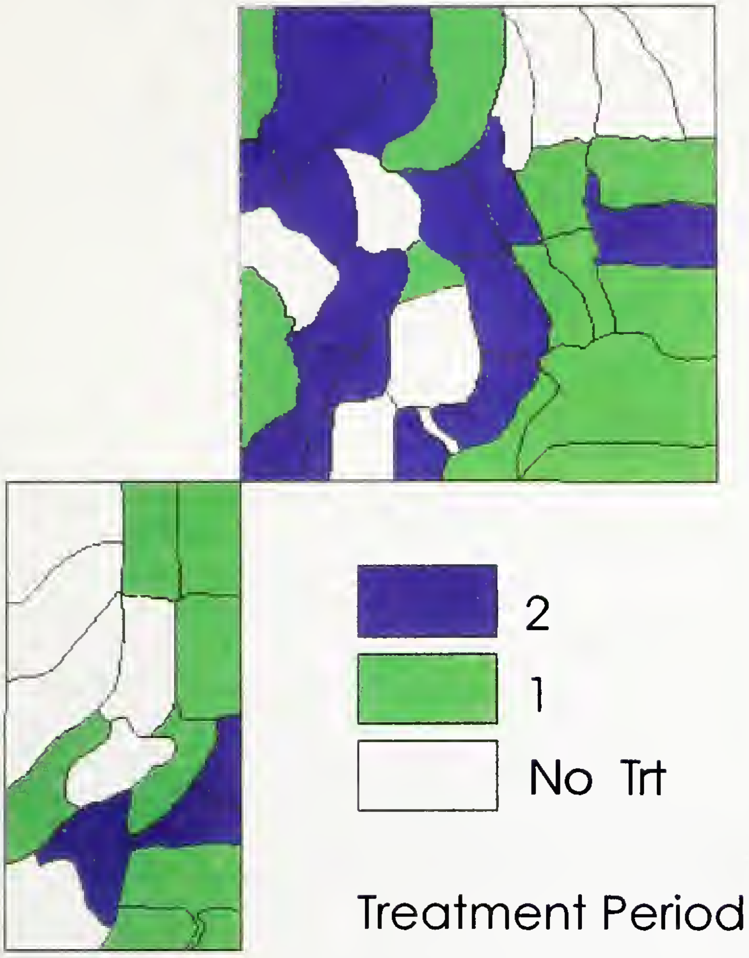

Figure 3—Treatment units accessed by period in a management scenario.

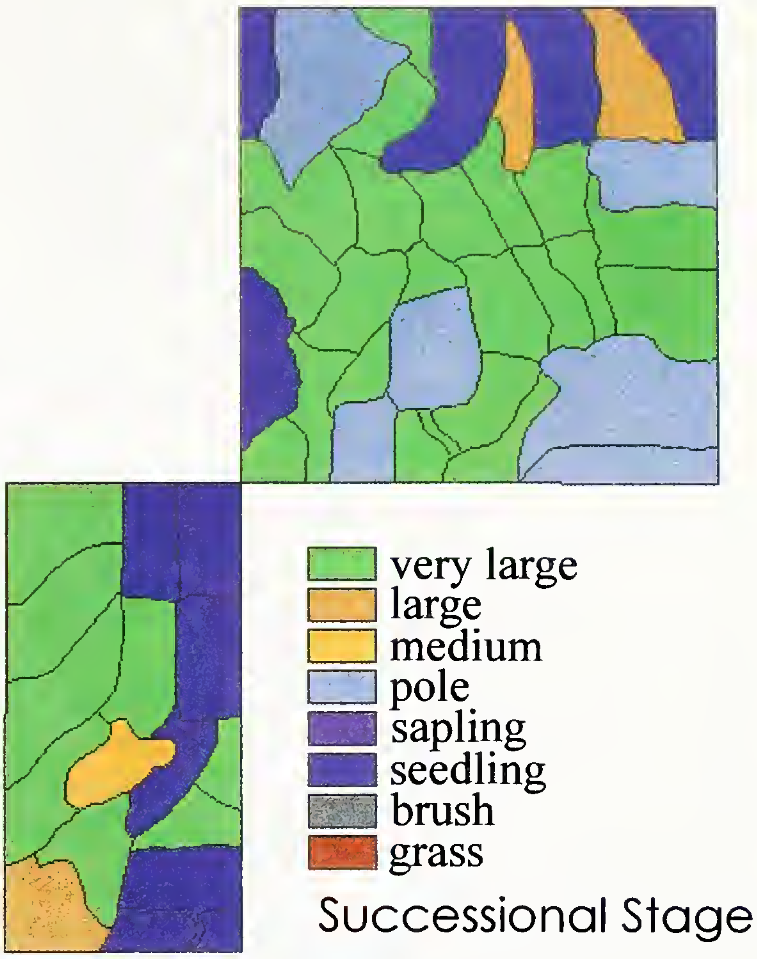

Figure 4—Distribution of successional stages across treatment units in period 1 following management activities.

longer time. Benchmark runs have been made for a 50,000-acre planning model having approximately 6,000 constraints and 6,000 decision variables (columns) with up to 2,000 integer variables. In these tests feasible mixed-integer solutions within 10 percent of the mixed-integer optimal could usually be obtained within 2 hours; often within 20 to 30 minutes. These tests were made using a 486-33 MHz machine with 8 MB of RAM, and an earlier version of the MPSIII/pc software. Faster processing times can be expected with the current version of MPSIII/pc, with more RAM, and with faster microprocessors.

Software Status and Availability

MAGIS is currently in a beta test version with a scheduled release during the first quarter of 1996. For more information please contact:

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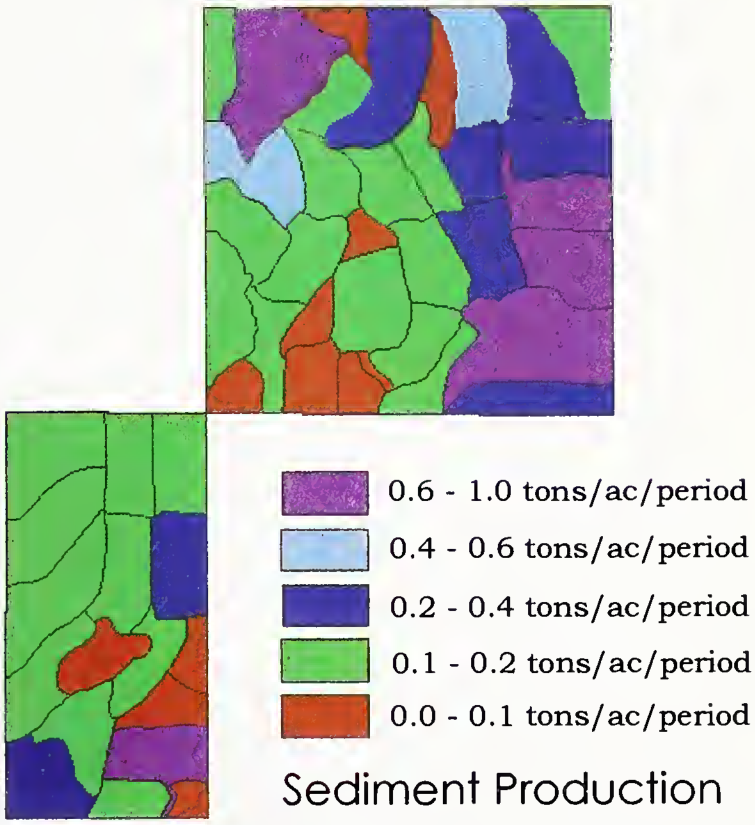

Figure 5—Distribution of sediment production across treatment units in period 1 resulting from management activities.

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